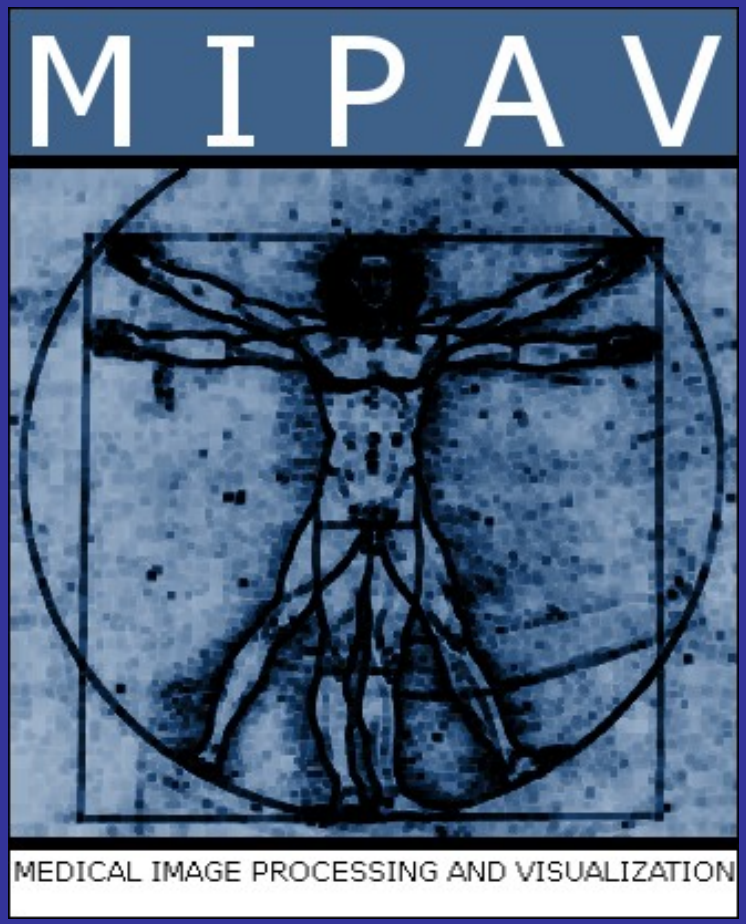

http://mipav.cit.nih.gov

Image Processing Algorithms with MIPAV

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Biomedical Image Processing Research Services Section (BIRSS)

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MIPAV algorithms

- Filters
  - Gaussian blurring, Laplacian, curvature, other higher order derivatives, median, gradient magnitude, edge detection, etc.
  - Anisotropic diffusion
  - Frequency domain (FFT, etc)
- Morphological operators (2D and 3D)
  - erode, dilate, open, close, distance, etc.
- Segmentation
  - Fuzzy C-means
  - Level set
  - Thresholding
  - Watershed
- Registration
  - Landmark – least squares, Thin-plate spline
  - AFNI registration technique
  - General Linear Registration (multiple cost function including, normalized and standard mutual information, correlation, least-squares, etc) and user selectable degree of freedom (DOF, 12 – affine, 6 – rigid,)

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MIPAV algorithms (cont.)

- Image transformations or resampling
  - nearest neighbor, tri-linear, sinc, bSpline and others interpolation methods.
- Skull stripping (BSE, BET)
- Midsagittal line alignment
- Histogram equalization and matching
- Shading correction
- Reslice 3D dataset to isotropic voxels
  - linear, cubic, cubic bspline.
- Microscopy
  - FRET, FRAP, Co-localization
- Surface extraction
- And more...

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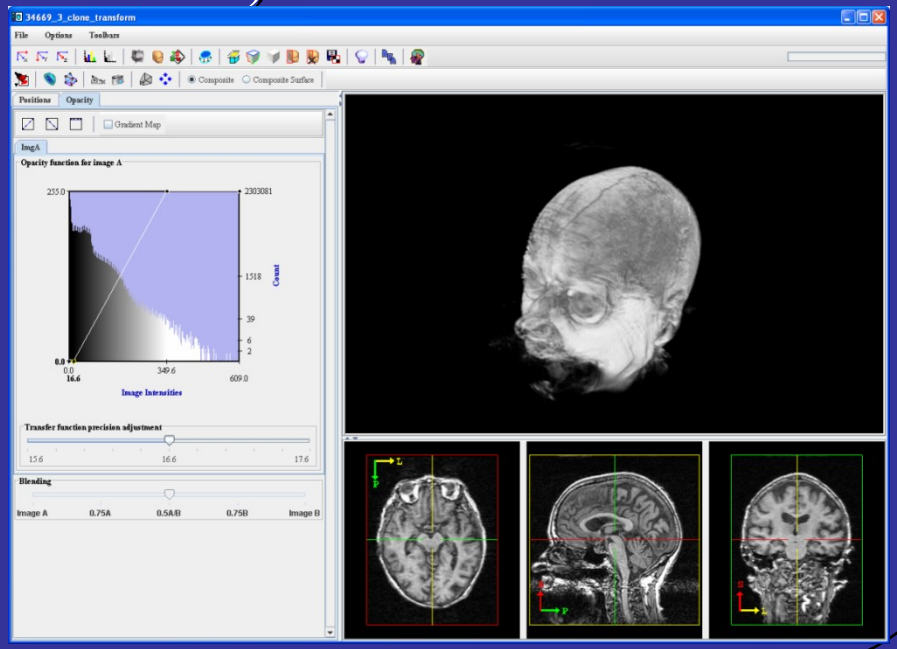
Image Processing Dimensionality

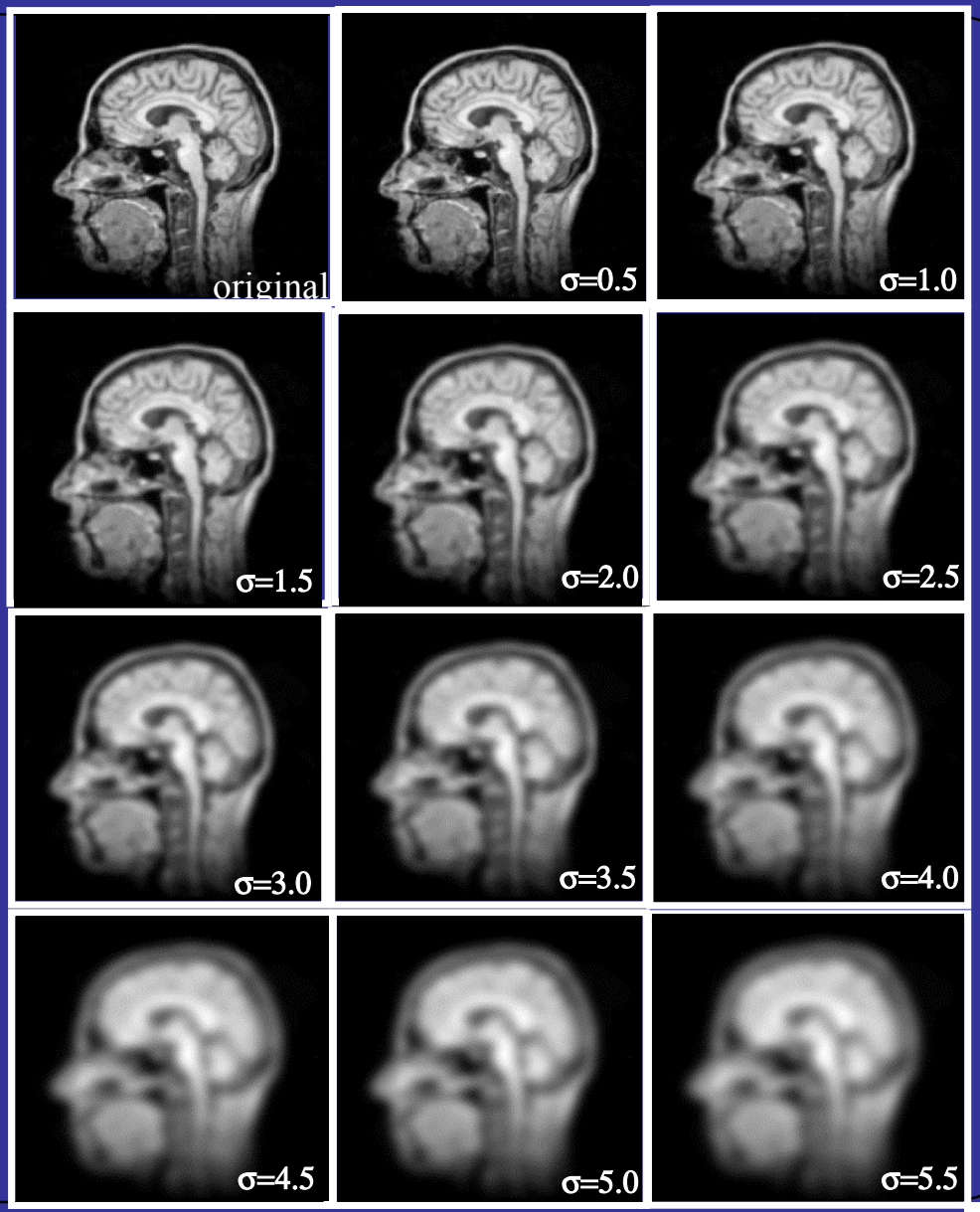
- 2D - image plane (slice)
- 2.5D - (3D treated as set of slices)
- 3D - (3D processed as volume)
- 3.5D
- 4D



Filters

Scale-space

- Scale-space of the MR image of the head
- Produced by convolving the Gaussian of increasing standard deviation with the MR image

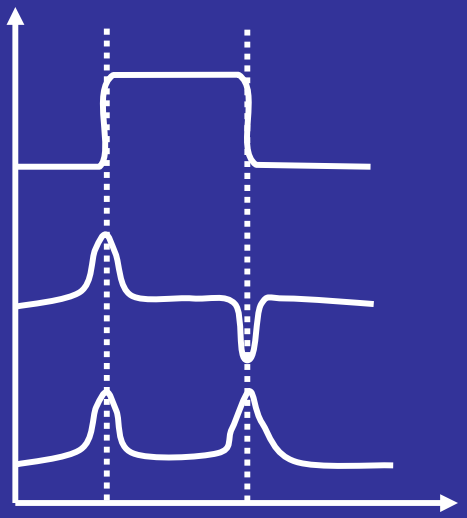


Gradient Magnitude
1D Example

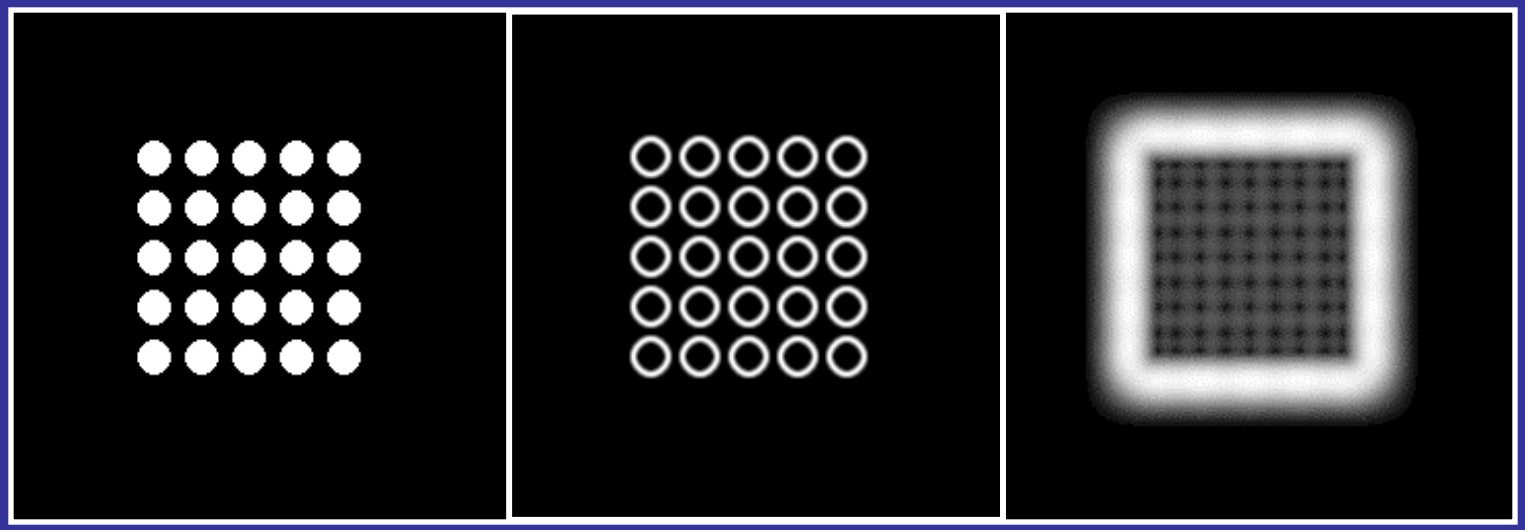
Original signal

First derivative

Gradient magnitude



Importance of scale_



(a)

Binary Object -
square formed from disks

(b)

Gradient Magnitude
$\sigma = 1.0$

(c)

Gradient Magnitude
$\sigma = 10.0$

$$I_{GM}(x,y) = (I_x^2 + I_y^2)^{0.5}$$ - gradient magnitude

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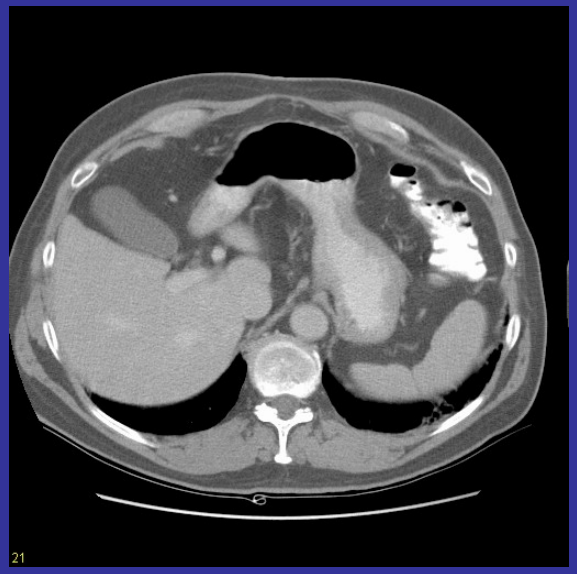
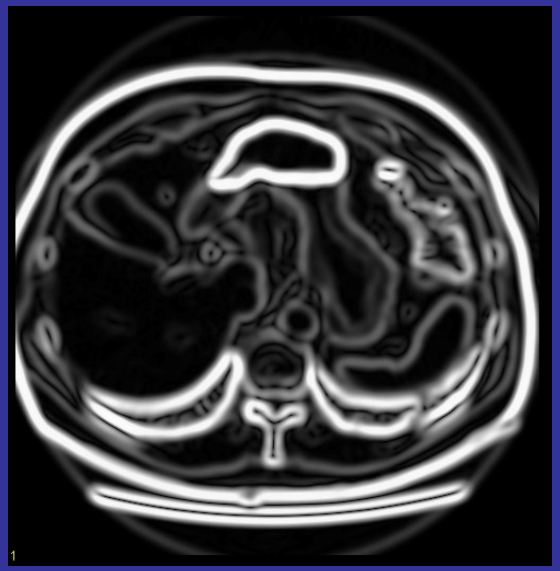
Importance of scale (Gradient Magnitude of CT image)



Axial CT image

Gradient magnitude (sigma = 1.0)



Gradient magnitude (sigma = 4.0)

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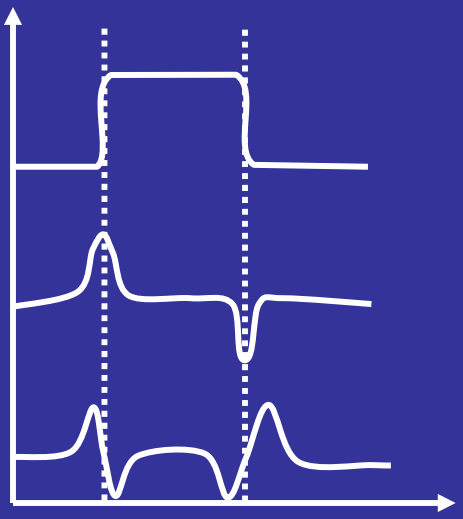
Laplacian

Original signal

First derivative

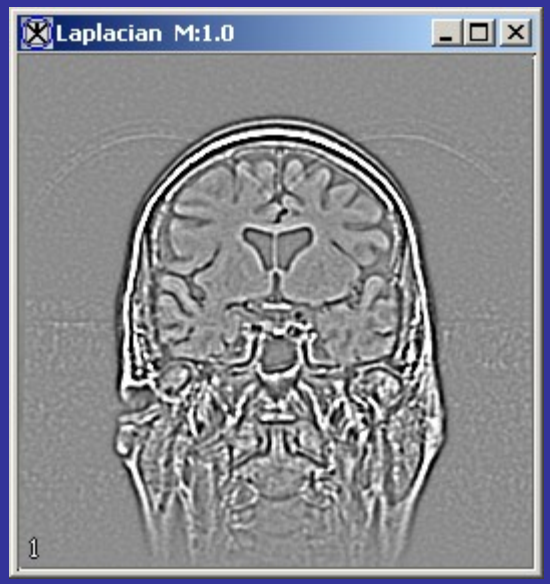
Second derivative



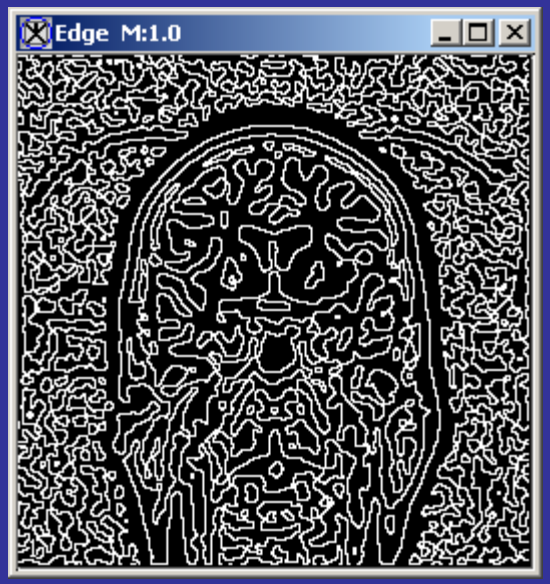
$$\nabla^2 I = I_{xx} + I_{yy}$$

Laplacian

Original MR Image



Laplacian of MR Image



Zero crossings

Median Filtering

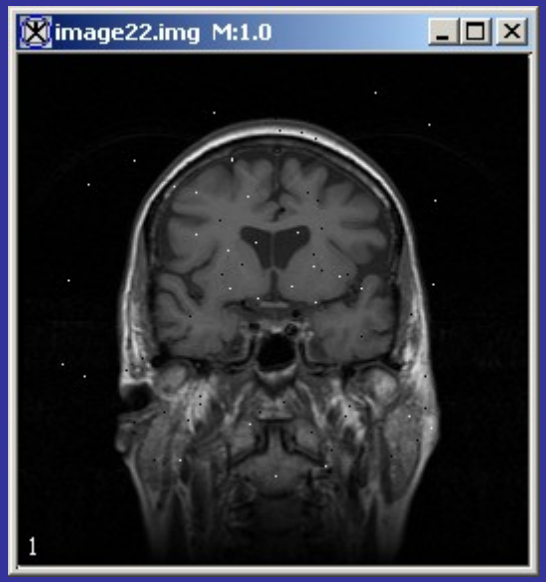


Image with noise

Median filter image

Gaussian smoothed image

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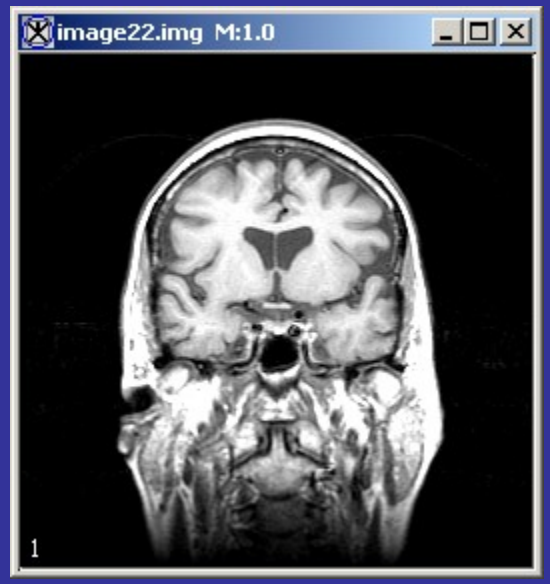
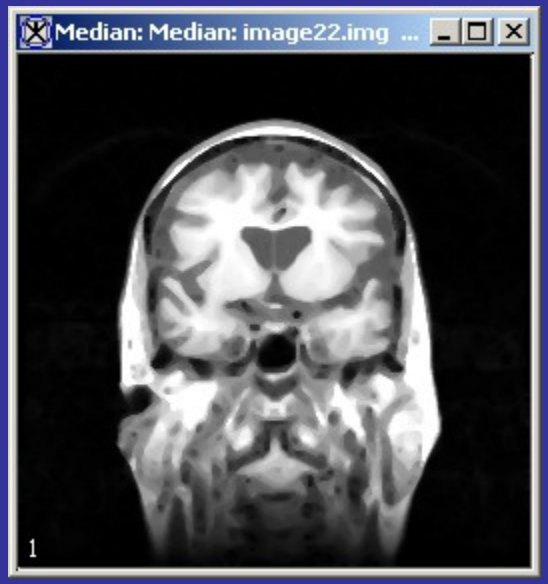
Median Filtering



Original MR Image

1 Iteration



5 Iterations

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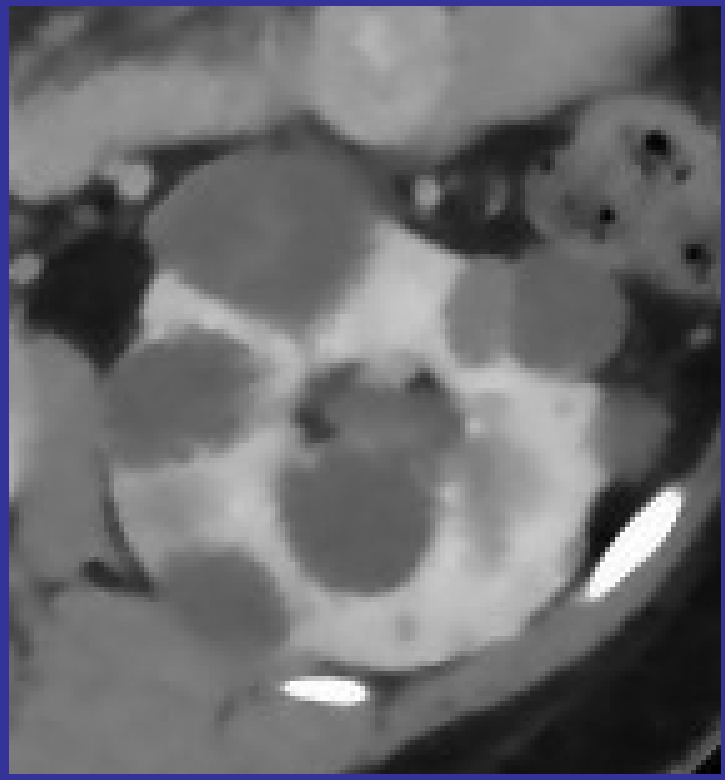
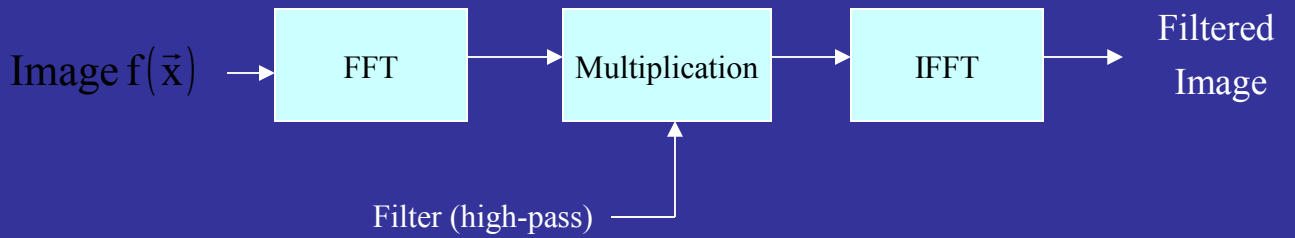
MIPAV: Example of Ansiotropic Diffusion on CT Images of the Kidney.

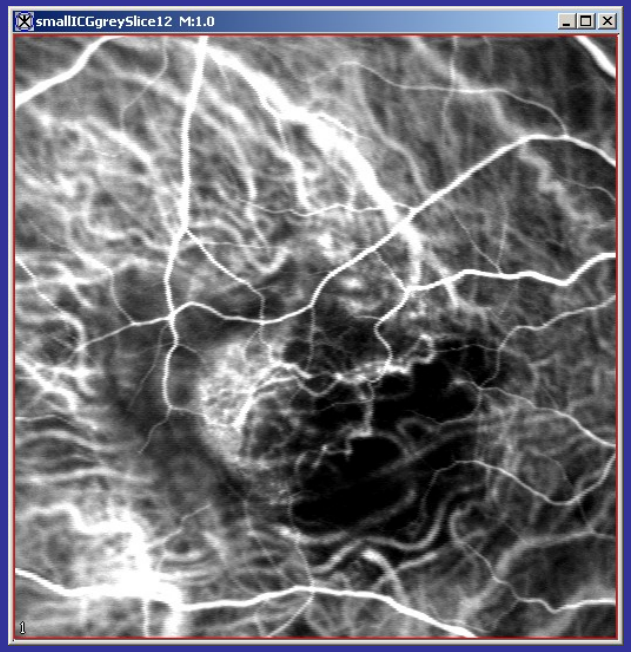
Before

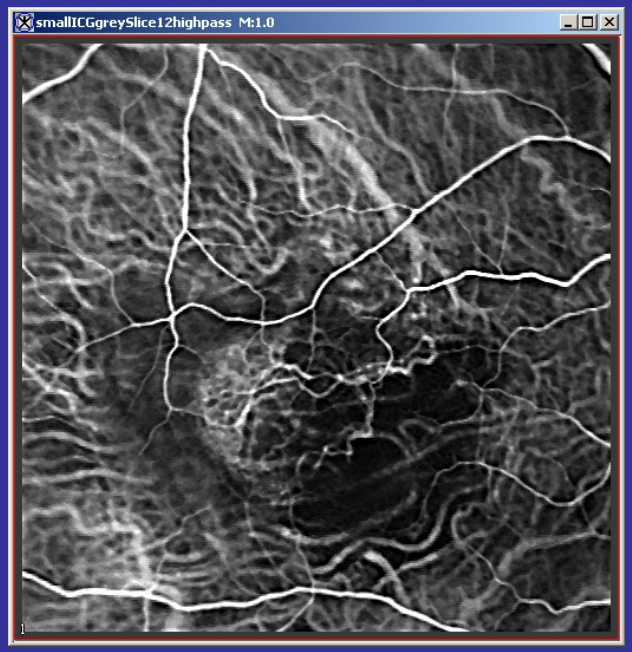


After

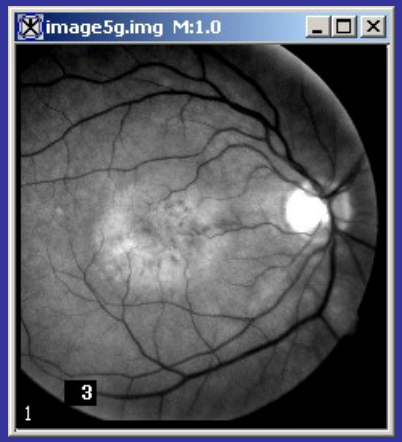
Fourier Transform Examples

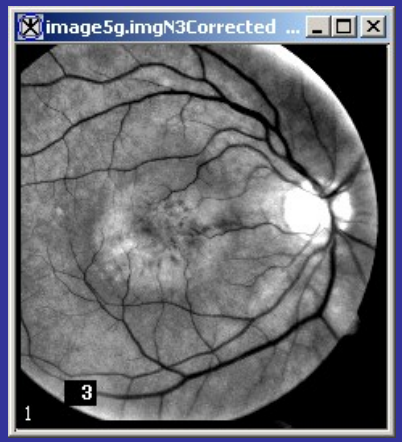


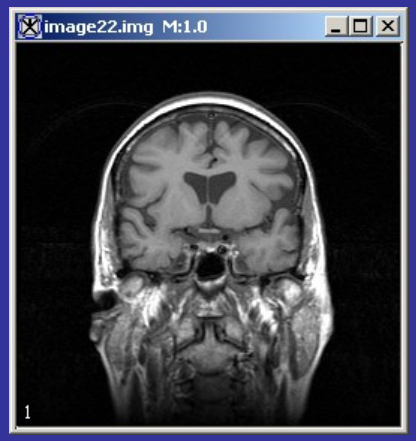


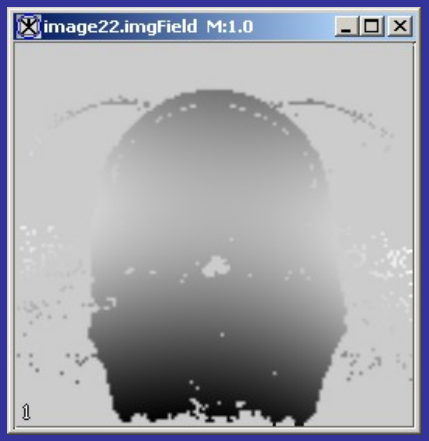


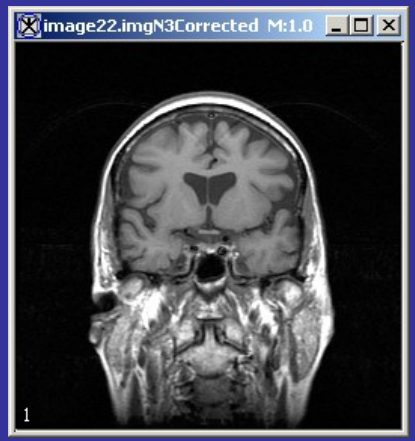
Shading correction











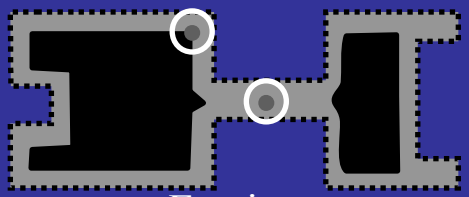
Morphology

Mathematical Morphology (Set theory)

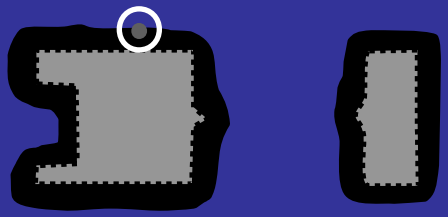
- Erosion
- Dilation
- Opening
- Closing
- Distance maps
- Skeletonization

Mathematical Morphology

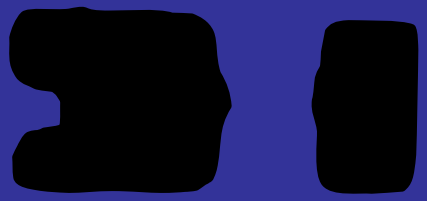
Source object



Erosion



Dilation



Result: Erosion + Dilation = Opening

Opening_

Structuring Element

0	1	0
1	1	1
0	1	0

2D 3x3 structuring element

0	0	0
0	1	0
0	0	0

0	1	0
1	1	1
0	1	0

0	0	0
0	1	0
0	0	0

3D 3x3x3 structuring element

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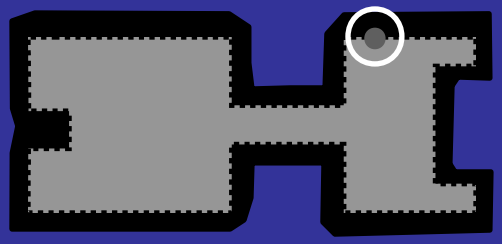
Mathematical Morphology

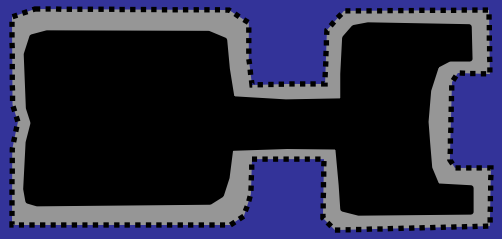
Closing_

Source object

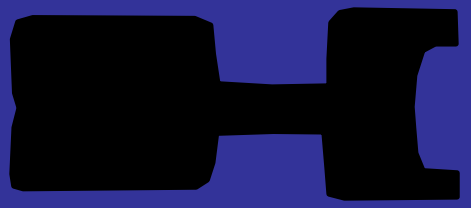
Structuring Element



Dilation



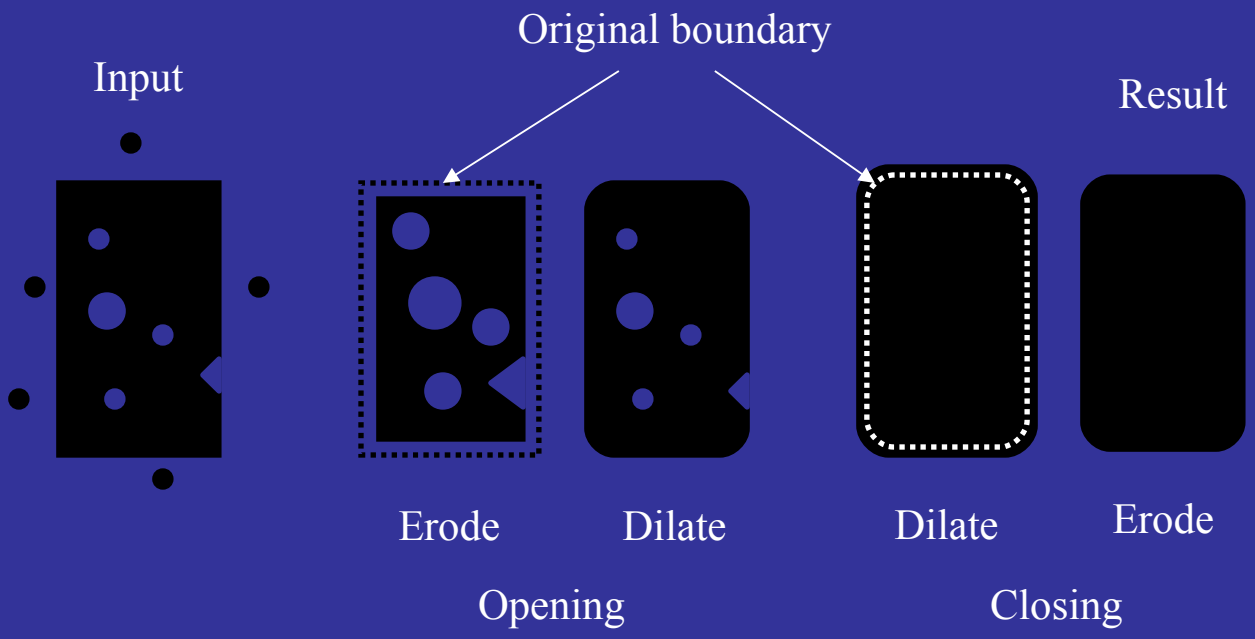
Erosion



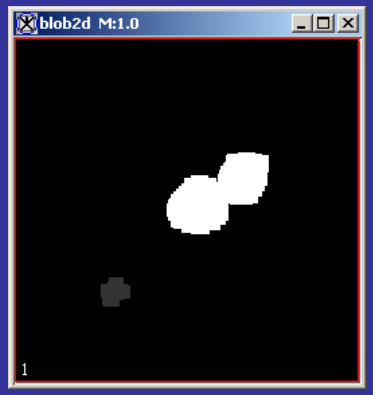
Result: Dilation + Erosion = Closing

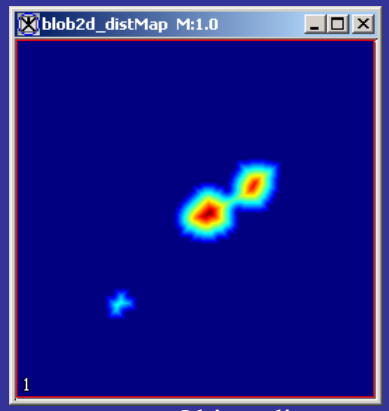
Mathematical Morphology

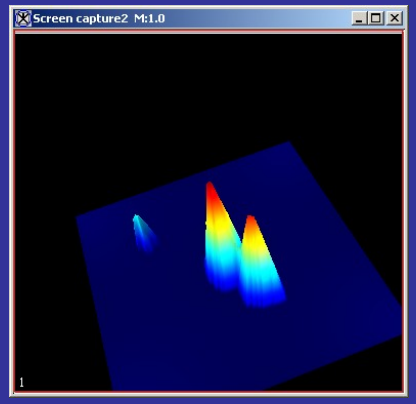
Noise Removal_



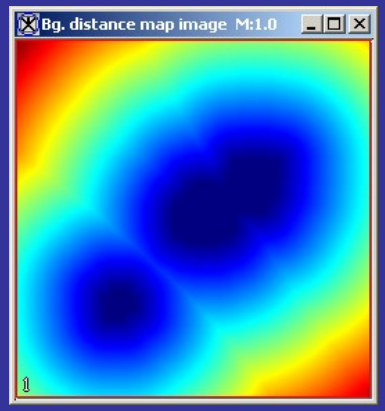
Distance transform_

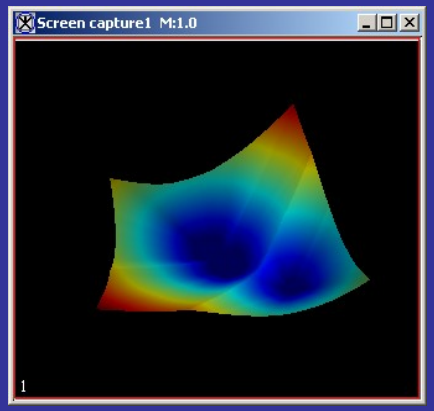






Object distance - minimum Euclidian distance
from any edge to a point interior to the object





Background distance - minimum Euclidian distance
from any edge to a point exterior to the object (i.e. background)

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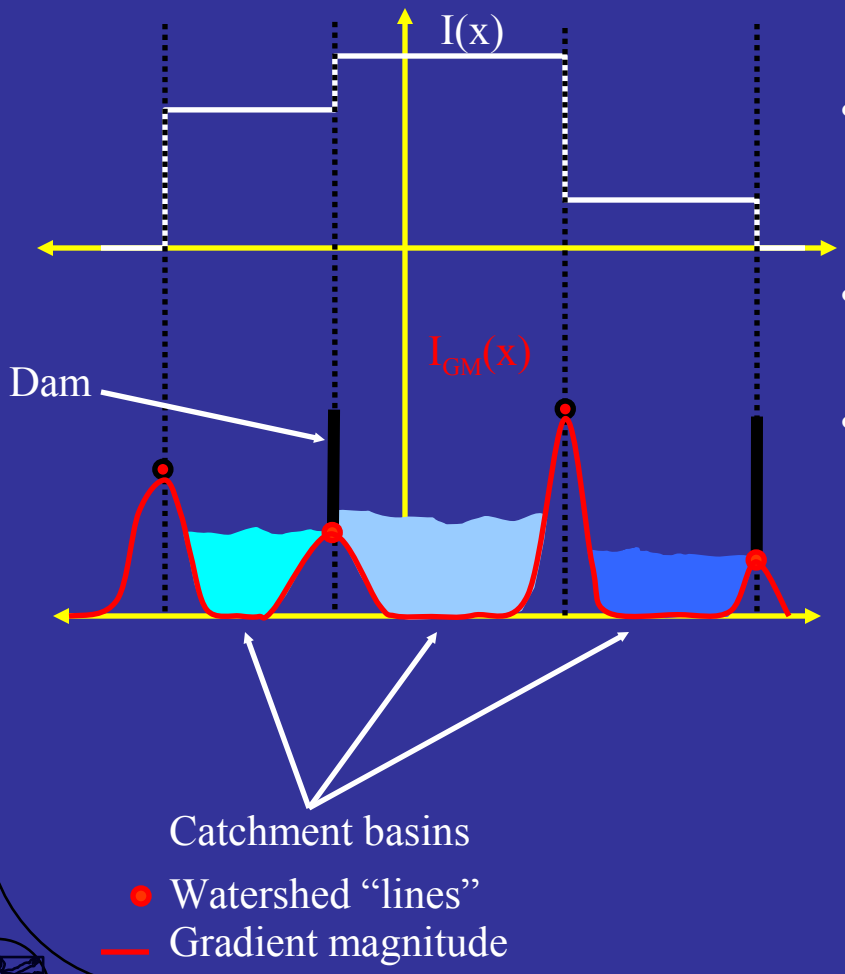
Segmentation

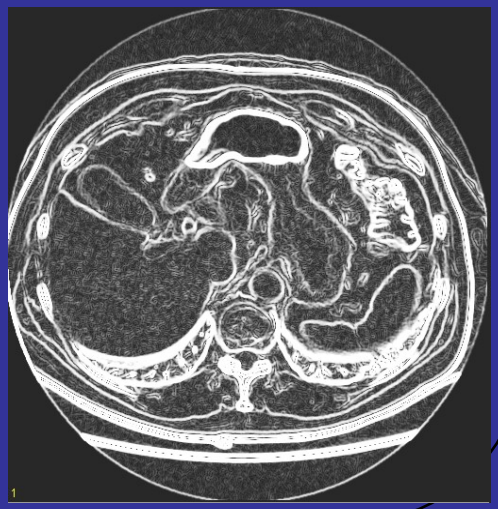
Watershed Segmentation

- Watersheds are a classic field of topography.
- Example of a watershed: *Great Divide* of the U.S.
  - A drop of water falling one side flows down until it reaches the Atlantic ocean, whereas a drop falling on the other end flows until it reaches the Pacific ocean.
- The above two watersheds or catchment basins are separated by what is termed the watershed line.
  - Catchment basins: minima of the watershed
  - Watershed line: maxima of the watershed

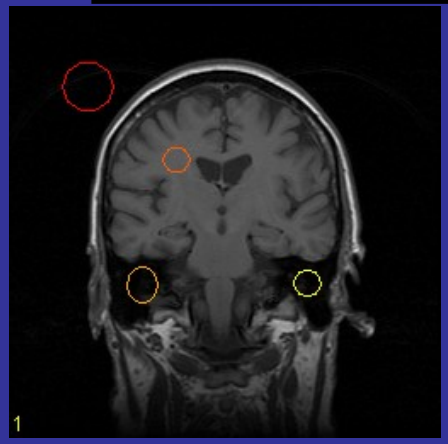
Watershed Segmentation



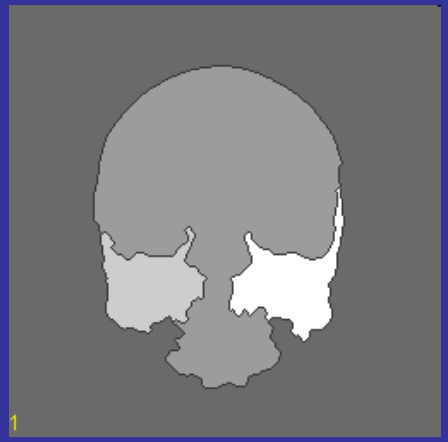
- Find the lowest point in each basin and begin "flooding".
- When two basins meet a watershed point (1D) is identified and a dam is formed.
- Continue flooding until all basins and watershed points are formed.
- Note: this method can produce over segmentations.



Watershed Segmentation: Interactive



MRI image with ROIs



Segmented basins

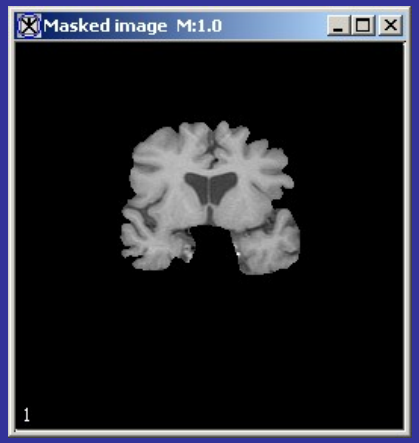
- Find the lowest point in each basin identified by a Region of Interest (ROI) and force the gradient magnitude to zero at all ROIs. Begin "flooding" in those regions.
- When two basins meet a watershed line (2D) is identified and a dam is formed.
- Continue flooding until all ROI basins until all regions are flooded.

Voxel Classification

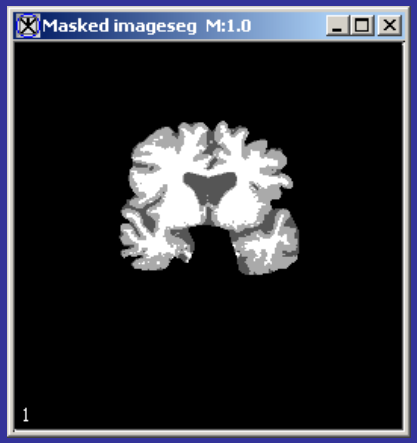
- Groups of voxels are not physically connected then the segmentation technique is termed voxel classification and voxels sets are referred to as **classes**

- Cluster methods do not inherently incorporate spatial information and therefore can be sensitive to factors like intensity inhomogeneities.

Fuzzy C-means



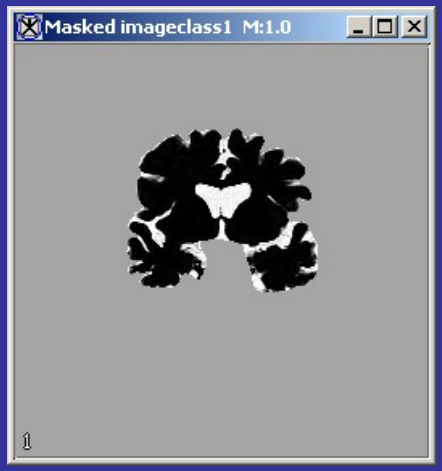
T1 – MRI



Hard segmentation – G,W,CSF

Fuzzy Gray

Fuzzy White



Fuzzy CSF

Registration

Registration

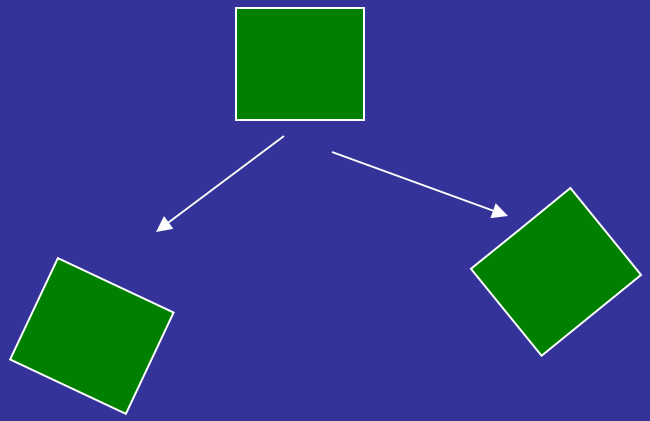
- Two main classes of problems
  - Intra-modality
    - Intra - patient
    - Inter - patient
  - Inter-modality
    - Intra - patient
    - Inter - patient
- Two main methods
  - Extrinsic - landmark methods using surfaces, lines, points.
    - Can be automatic or manual identification of landmarks.
  - Intrinsic – image intensity base using voxel similarity measures (i.e. Cross correlation, mutual information, etc.)

Registration

- Transformation matrix establishes geometrical correspondence between coordinate systems of different images. It is used to transform one image into the space of the other.
- Many different types but generally in biomedical imaging only a few classes are use:
  - Rigid body
  - Global rescale
  - Affine
  - Non-linear

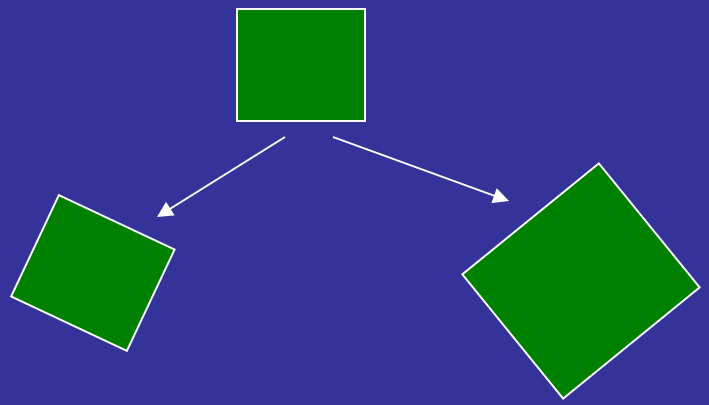
Registration

- Rigid-body transformations include translations and rotations. Preserve all lengths and angles.
  - 2D -> 3 Degrees of Freedom (DOF)
  - 3D -> 6 DOF (3 translation and 3 rotation)



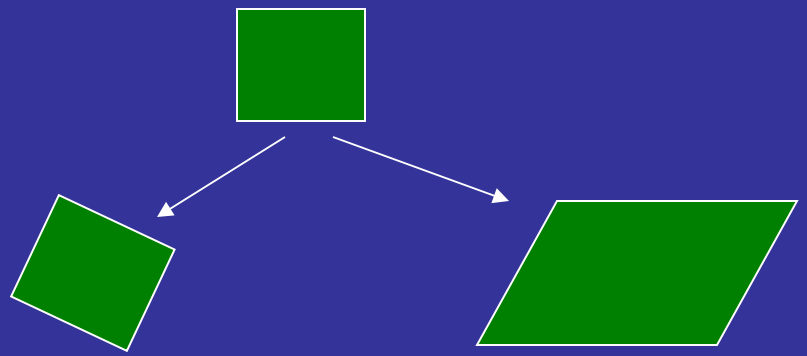
Registration

- Global rescale transformations include translations, rotations, and a single scale parameter. Preserve all angles and **relative** lengths.
  - 2D -> 4 DOF (2 translation + 1 rotation + 1 scale)
  - 3D -> 7 DOF (3 translation + 3 rotation + 1 scale)



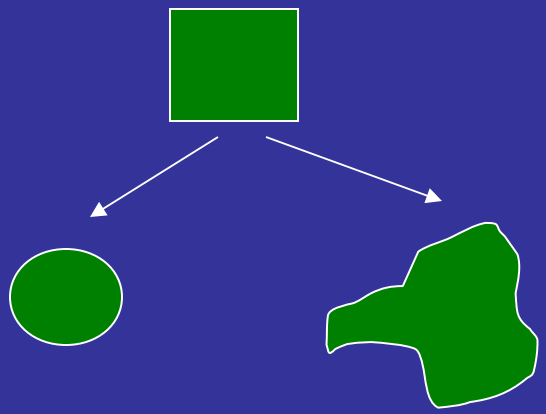
Registration

- Affine transformations include translations, rotations, scales, and/or skewing parameters. Preserve straight lines but necessarily not angles or lengths.
  - 2D -> 5 or 7 DOF (2 translation + 1 rotation + 2 scale + 2 skewing)
  - 3D -> 9 or 12 DOF (3 translation + 3 rotation + 3 scale + 3 skewing)



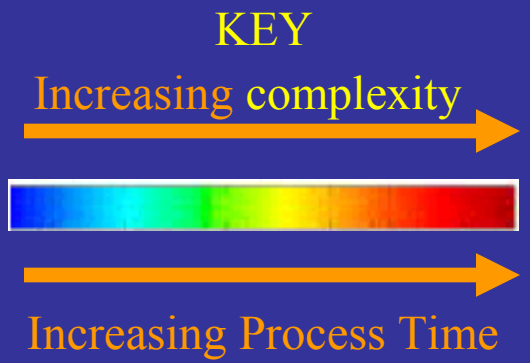
Registration

- Non-linear transformations are local deformations and therefore they are the most general.
  - 2D -> many DOF
  - 3D -> many DOF

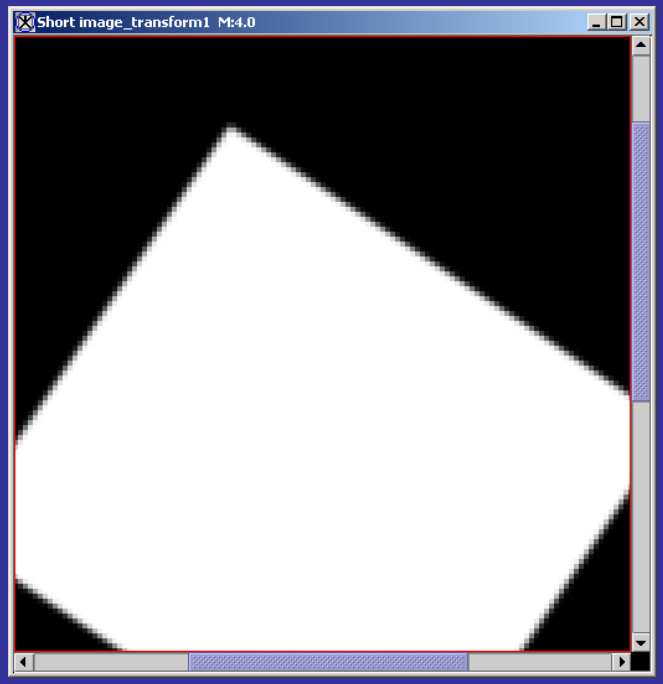


Interpolation Options

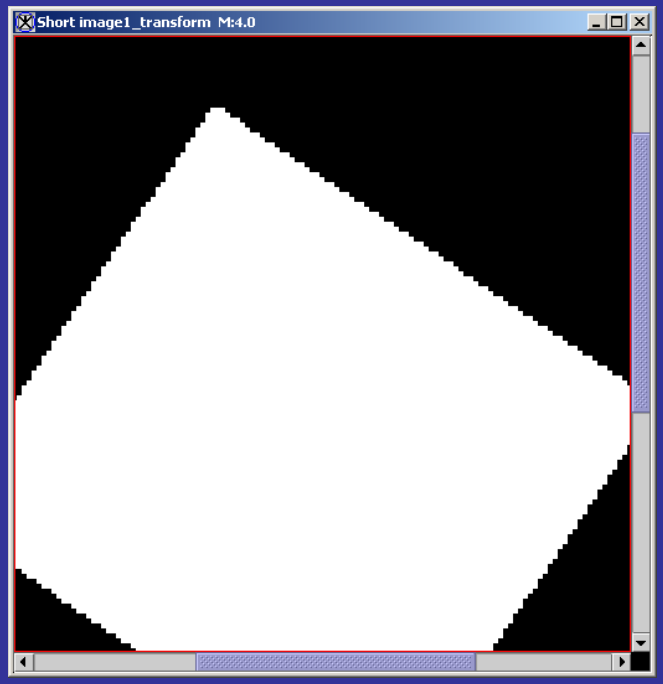
- Trilinear
- Cubic Lagrangian
- Quintic Lagrangian
- Heptic Lagrangian
- Windowed Sinc
- Bspline 3rd Order
- Bspline 4th Order



Registration



4th Order Bspline interpolation



Nearest neighbor interpolation

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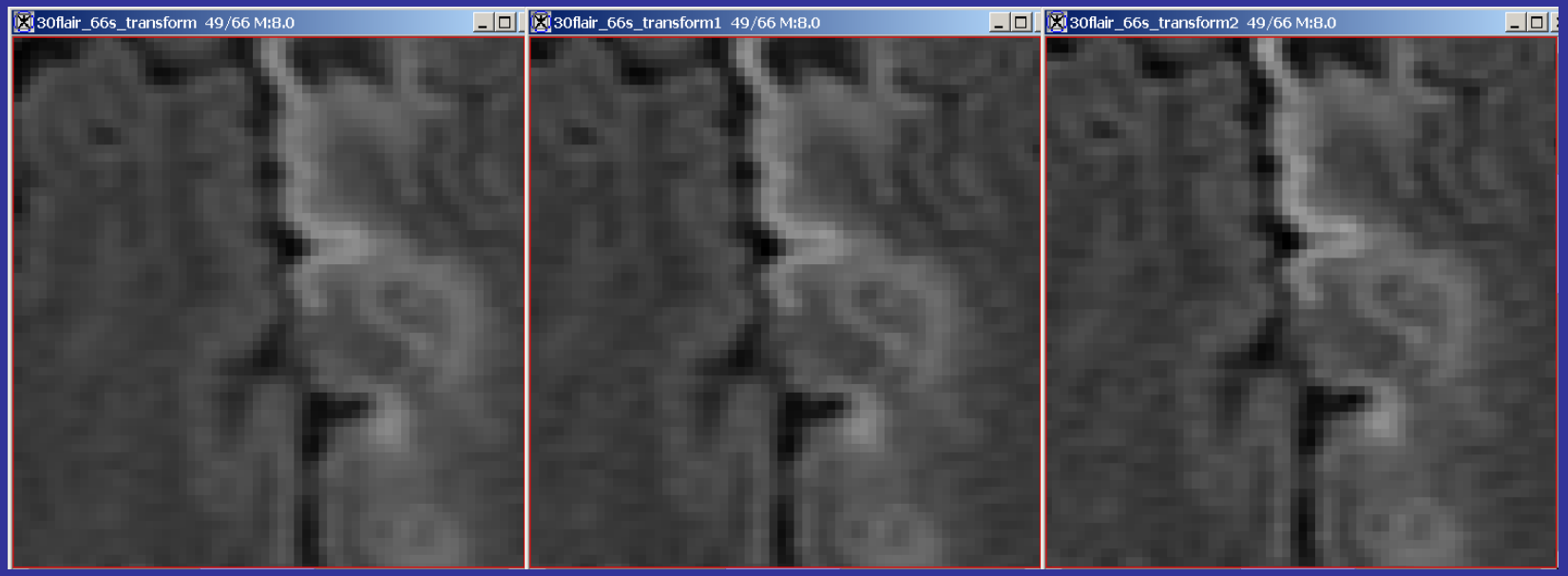
Interpolation Differences



Trilinear Cubic Lagrangian Windowed Sinc

Contrast increasing

Registration

- Extrinsic Landmark based methods
  - can require user interaction
    - Manual identification – user intensive
    - Automatic identification can be problematic but depends on task and modality
  - can be shown to be less reliable and accurate than intensity based methods. Depends on modality and task.
  - once landmarks are identified registration is very fast.

Registration

- Intrinsic – image intensity at voxels
  - "Best" registration is identified by the minimum of some "cost" function.
  - The cost function is an assessment of how good the alignment between the objects to be registered.
    - A high cost should equate to a poor alignment
    - A low cost should equate to a good alignment
  - Goal
    - Find the transformation (matrix) which minimizes the cost function.

Registration

- Cost functions
  - Intra-modality with consistent mapping of intensity values
    - Least squares
  - Inter-modality or Intra-modality where mapping of intensity values might vary.
    - Normalized correlation
    - Correlation ratio
    - Normalized mutual information

Registration

- Normalized Mutual Information (NMI) – is base on the entropy of the images (histogram) and the relationship between voxels – joint entropy.

  $NMI = (H(x) + H(y)) / H(x,y)$ $H(\ ) = \text{entropy}$

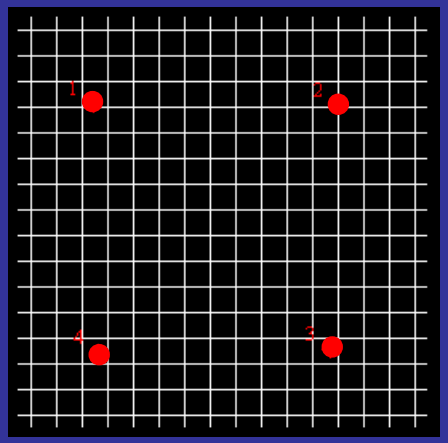
  $= - \sum p_i \log p_i$

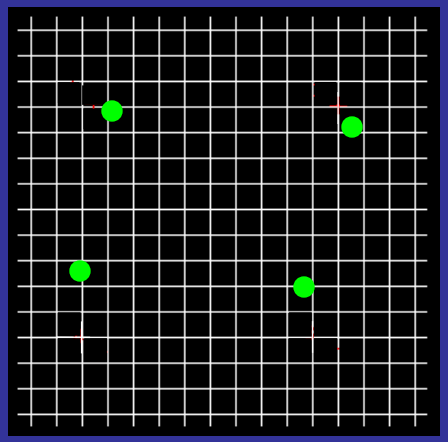
  where p = (histogram count in bin) / total count

- Entropy is a measure of the disorder or unavailability of energy within a closed system.

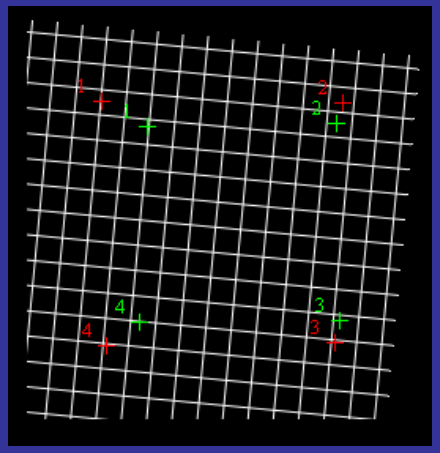
- Entropy will have a maximum value if all values of the histogram have equal probability of occurring (flat histogram) and a minimum when all except one value has a probability of zero.
  - For example, blurring an image reduces noise and thus sharpens the images histogram, resulting in reduced entropy.

Landmark Registration Techniques

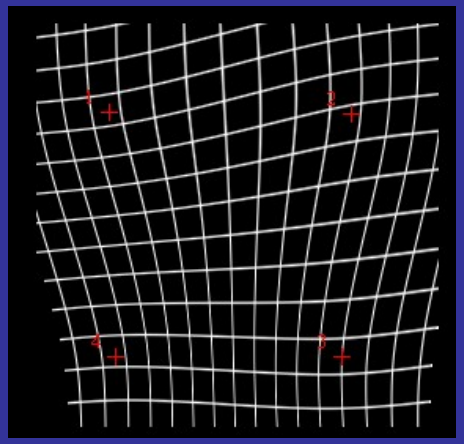




Grid with landmarks points



Least squares registration (rotation & translation: rigid)



Thin plate splines registration (rotation, translation and scale: non-linear)

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Registration

Least-Squares Fitting of 2 Point Sets

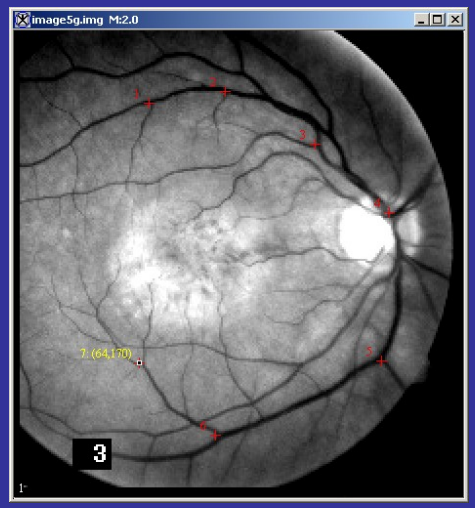

Image A with 7 landmarks

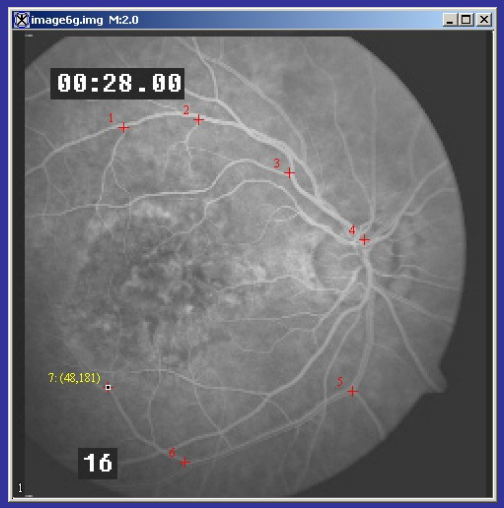

Image B with 7 homologous landmarks

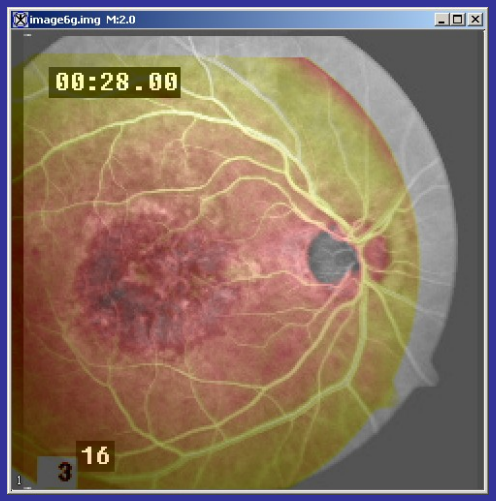

Image A (heated metal LUT) registered and overlaid onto Image B (gray LUT)

Images supplied by Karl Csaky

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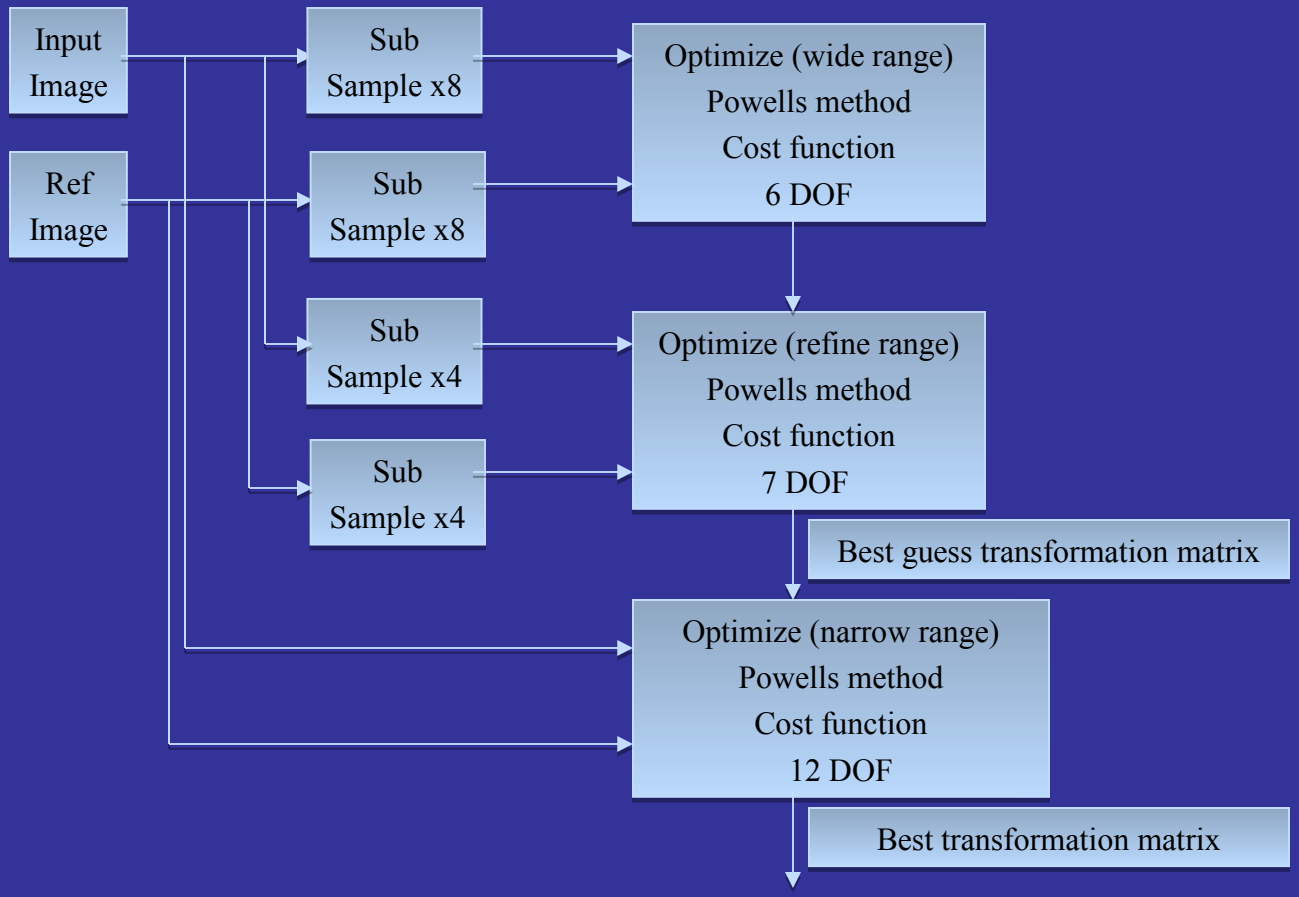
Registration



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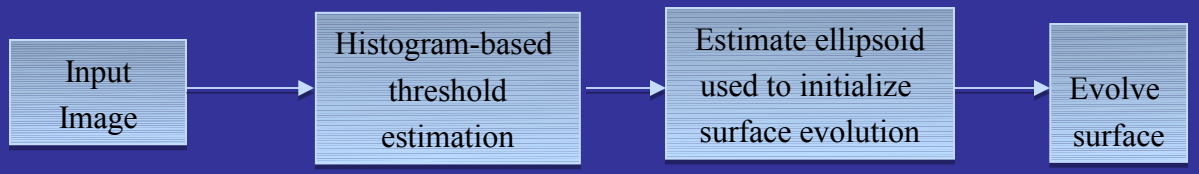
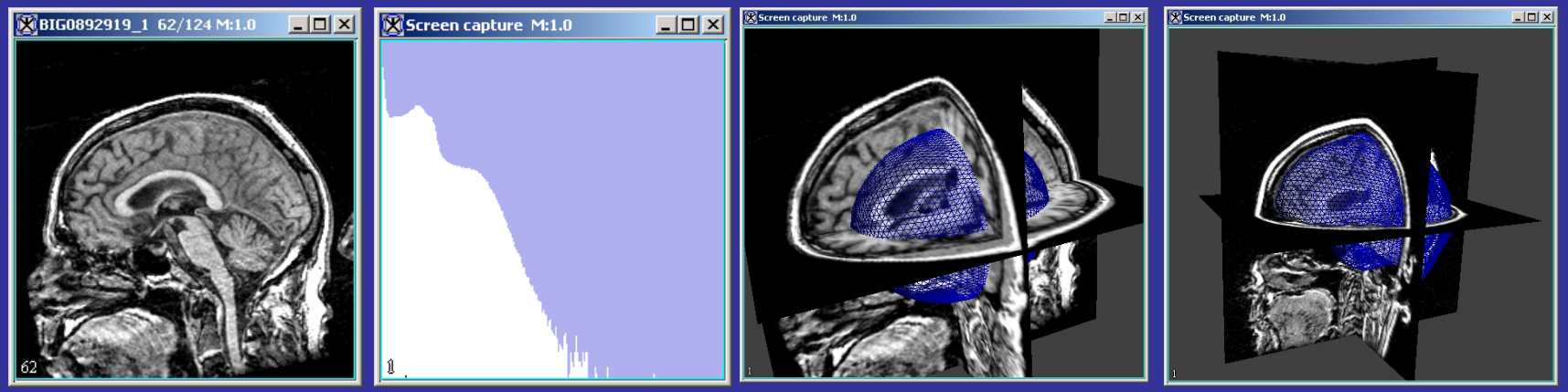
Skull stripping - BET





Based on: Brain Extraction Tool (BET)

MIPAV Utilities

- Image conversion
  - Gray <==> RGB
  - 4D <==> 3D
  - Between data types
- Image cloning
- Rotation / flipping
- Cropping
- Mask-based quantification
- Intensity projection generation
- Slice extraction / manipulation
- Intensity replacement
- Invert intensity
- Add padding
- Correct spacing
- Image math (operations performed on one image – abs. value, addition, log, etc.)
- Image calculator (operations performed using two source images – difference, multiplication, average, etc.)